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THE ROLE OF A NOCTURNAL LOW-LEVEL JET IN THE UPPER MIDWEST SEVERE CONVECTIVE STORMS OF 4 SEPTEMBER 1992

Alan Gerard[1]
National Weather Service Office
Columbus, Ohio

1. INTRODUCTION

During the early morning hours of 4 September 1992, a convective complex developed across parts of southern Minnesota and extreme western Wisconsin. These thunderstorms were quite strong, producing heavy rainfall and hail. The storms were severe over extreme southeastern Minnesota just south of Minneapolis, MN (MSP), where 3/4 in or greater sized hail was reported in several locations.

These thunderstorms developed in an area where many of the usual severe weather indices did not initially appear favorable for the development of severe convective storms. However, a strong nocturnal low-level jet developed over this area during the early morning hours and influenced several factors regarding the development of the convective system. This paper will illustrate how the low-level jet altered the storm environment in such a way as to support the development of severe convection.

2. SUMMARY OF THE EVENT

Radar composite charts from the morning of 4 September 1992 depicted no convection over Minnesota through 0835 UTC (not shown). By 0935 UTC, however, thunderstorms had developed over the central portion of the state, with maximum radar returns of D/VIP (Digital Video Integrator Processor) 5 (50-57 dBZ) and maximum tops of 42,000 ft (Fig. 1).

The area of thunderstorms continued to expand, moving southeast along the 1000-500 mb thickness contours, as depicted on the 12-h NGM thickness forecast valid for 1200 UTC 4 September (Fig. 2). By 1135 UTC, the convection covered much of the southern two-thirds of Minnesota (Fig. 3). Around this time (1130 UTC), 1 1/2 in hail was reported in Dakota County, just south of Minneapolis.

The thunderstorms continued to move across southern Minnesota during the morning hours, with several reports of hail. One-eighth inch hail fell at the Minneapolis-St. Paul Airport at 1231 UTC. Reports of hail meeting severe criteria, obtained from

[1]current affiliation: National Weather Service Forecast Office, Cleveland, Ohio

National Weather Service Local Storm Reports (LSR), included: 3/4 in hail in Dakota County at 1210 UTC, 1 3/4 in hail in Rice County at 1235 UTC, and 7/8 in hail in Goodhue County at 1325 UTC. All of these reports came from the area just south of Minneapolis. The thunderstorms also produced frequent lightning and heavy rain. Satellite precipitation estimates of around 1 in of rain between 1130 and 1230 UTC were made by the NESDIS Synoptic Analysis Branch for several counties in east central Minnesota and west central Wisconsin.

After 1500 UTC, a general weakening trend in the convection was indicated by radar and lightning depiction charts. Severe weather was not reported after 1325 UTC, and at 1706 UTC, the National Severe Storms Forecast Center (NSSFC) canceled a Severe Thunderstorm Watch, which had been issued at 1301 UTC for this area.

3. SYNOPTIC SITUATION

The 1200 UTC 4 September 500-mb analysis (Fig. 4) shows a trough over the western United States, with a weak ridge over the Northern Plains. The air was dry at 500 mb over the Northern Plains (e.g., the dewpoint depression at St. Cloud, MN [STC], was greater than 30°C).

The main feature to note on the 700-mb chart (Fig. 5) was the drier air (dewpoints below 0°C and dewpoint depressions greater than 10°C) advecting into Minnesota from the southwest. Such a dry intrusion at 700 mb is often favorable for the development of severe convection, especially when it occurs in an environment of strong directional and speed shear in the wind field between the surface and 700 mb (Miller 1972). This was the case on 4 September.

At 850 mb (Fig. 6), a low pressure center was located over southern Saskatchewan. An anticyclone extending from the surface (Fig. 7) to 850 mb was moving east of the Plains Region, resulting in a return southerly flow over the central United States. As discussed by Doswell (1982), this is a typical synoptic situation in which a low-level jet may develop.

A 50-kt low-level jet is evident on the 1200 UTC 4 September 850 mb analysis (Fig. 6). The jet axis extended across Nebraska, eastern South Dakota, and into southwestern Minnesota. This jet was much stronger than that observed at 0000 UTC (not shown), when the low-level wind maximum at 850 mb was only 30 kt and located over eastern South Dakota.

Regarding low-level moisture at 1200 UTC, 850-mb dewpoints over the area where the convection developed were less than 8°C, and surface dewpoints were at or below 55°F. These relatively low dewpoints are generally considered weak for the development of severe convection (Miller 1972). To the south of the warm front, the low-level moisture was more abundant, with 850-mb dewpoints of 8 to 12°C and surface dewpoints of 55 to 60°F. These dewpoints are considered to be moderate for severe convective development (Miller 1972). The air south of the warm front was transported by the low-level jet into the area where the convection developed. In order to obtain an accurate depiction of the low-level moisture and instability present, this area should be analyzed to determine the potential for convection.

4. THE LOW-LEVEL JET

4.1. The Overnight Strengthening of the Low-Level Jet

An examination of the 1200 UTC 4 September 300-mb analysis (Fig. 8) showed an upper-level jet streak over central Canada. As previously discussed, the low-level jet was easily discernible at 850 mb at 1200 UTC (Fig. 6) over Nebraska, eastern South Dakota, and Minnesota. This area is well to the southwest of the exit region of the 300-mb jet streak. As has been discussed by Uccellini and Johnson (1979), and more recently by Rolinski and Moore (1992), when a low-level jet is coupled to and strengthened by an upper-level jet, the low-level jet lies in the exit region of the upper-level jet. This does not appear to be the case in this study.

Since the increase in strength of the low-level jet does not appear to be the result of coupling with an upper-level jet, another possibility as to why the jet strengthened was nocturnal decoupling. As discussed by Doswell (1982), nocturnal decoupling results in a dramatic reduction in friction immediately above the boundary layer, thereby causing an oscillation in the wind. This oscillation is dependent upon the value of the local Coriolis parameter, which creates an increase in wind speed, reaching a maximum during the early morning.

Evidence supporting this latter scenario is that the wind speed increased dramatically during the overnight hours and then weakened again during the day. Not coincidentally, the convection reached its peak around 1200 UTC and weakened thereafter through the morning hours. In addition, the St. Cloud, MN (STC), and Huron, SD (HON), soundings (Figs. 9 and 10) indicated that the maximum speed of the jet existed at the same height as that of the radiational surface inversion. This is often a characteristic of a nocturnal low-level jet (Brady and Brewster 1989). Furthermore, Rolinski and Moore (1992) found that the winds continued to increase with height above the low-level jet. However, in this case, both the Huron and St. Cloud soundings show a marked decrease in wind speed above the low-level jet before the speed increased again around 500 mb.

Hence, for this event the low-level jet was likely a result of nocturnal decoupling, rather than coupling with an upper-level jet streak. This is important for a forecaster to be aware of because, as in this case, when convection develops from a nocturnal low-level jet, the thunderstorms often reach peak intensity in the early morning when the low-level jet is the strongest. The storms then weaken in the mid- to late morning hours as the low-level jet weakens.

4.2. The Influence of the Low-Level Jet

Although the low-level jet was easily discernible on the 1200 UTC 850-mb analysis, it can be monitored by other means on a real-time basis. One accurate and timely manner is through the use of hourly wind profiler data, which was used by the NWS forecasters during this event (e.g., Fig. 11). More information on using profilers to track the nocturnal low-level jet can be found in Brady and Brewster (1989).

Another method, as discussed by Doswell (1982), is through the use of the geostrophic wind (Sangster) chart (AFOS graphic NMCGPH9AM). This product can be used to track the location and movement of the low-level jet maximum. The low-level jet in this case showed up particularly well, as can be seen on the Sangster chart for 1200 UTC 4 September 1992 (Fig. 12).

As mentioned earlier, an important factor associated with the low-level jet is the northward transport of moist and unstable air. A stability analysis for 1200 UTC 4 September 1992 (Fig. 13) showed that south of the warm front the air mass was fairly unstable with lifted indices of -3. The Total Totals Index ranged from 53 to 57. The analysis illustrated the unstable air that was available to be transported north by the low-level jet over the cool, stable air across Minnesota. This provided instability just above the surface, yielding the potential for elevated convection to develop.

As can be seen in this case, instability aloft is generally not revealed by traditional surface-based stability indices. A possible alternative for use in detecting instability aloft is the Theta-E index (TEI; Elson 1991). This index is determined by finding the greatest decrease in the equivalent potential temperature with height. At 1200 UTC at St. Cloud, the TEI was 15.5°C. This was much greater than the 5 to 10°C values suggested by Moore (1992) as indicative of the potential for convective development based above the surface.

Moore (1992) states that instability aloft can often by released through isentropic lift. The 1200 UTC 303 K (Fig. 14) isentropic analysis showed a 50-kt southwest wind over Minnesota blowing from higher to lower pressure, nearly perpendicular to the isobars, and across a strong pressure gradient. This type of flow pattern is indicative of strong upward motion (Moore 1992) and appeared to be a key factor in the development of convection.

The wind plotted on the isentropic chart is from the observed wind at the level closest to the isentropic surface. Since the height of the 303 K isentropic surface at St. Cloud (811 mb) was approximately the same height as the low-level jet, one can assume the low-level jet was responsible for the 50-kt wind indicated on the 303 K surface over Minnesota. Without the low-level jet, the strong isentropic lift would not have existed to release the convective potential of the unstable air present above the surface.

It is important to note that the vertical motion associated with the isentropic lift is not purely vertical, but rather occurs as the moist, unstable air is forced by the low-level jet to rise over the cooler, drier air near the surface. This meant that the convection did not develop at the source of convergence in the vicinity of the surface warm front, but rather at the point where the nose of the low-level jet intersected the warm frontal surface aloft. Doswell (1982) discusses the fact that convection usually develops at the nose of the low-level jet when the jet is interacting with a low-level boundary. These thunderstorms developed north of the surface position of the warm front and were based aloft, where the low-level jet was providing moisture and instability.

The fact that the convection was elevated is important to note, because it means that surface-based stability indices and forecast techniques may fail to give a complete picture of convective potential in this type of scenario. An example of the drawbacks in using surface-based indices in predicting the potential for elevated convection is the North Omaha, NE (OVN), 1200 UTC 4

September sounding. The Skew T/Hodograph Analysis and Research Program (SHARP; Hart and Korotky 1991) analysis of this sounding using the most unstable parcel, located at the top of the inversion, calculated a lifted index of -10. However, the stability analysis using a mean lower-level parcel (Fig. 13), only calculated a lifted index of -3. Although Figure 13 does show instability, it does not reveal the extreme instability present just above the surface. This demonstrates the importance of thoroughly examining the entire sounding in order to determine convective potential at a given location.

A final point to discuss in relation to the low-level jet is the effect it had on the low-level wind field. As can be seen in the hodograph for St. Cloud (Fig. 15), both the speed and directional shear were greatly enhanced by the presence of the low-level jet and were favorable for the development of severe thunderstorms. In fact, the 0-3 km helicity calculated by SHARP was 826 $m^2\ s^{-2}$. This was much greater than the values suggested by Davies-Jones et al. (1990) for tornadic activity. One possible explanation for the lack of tornadoes in this case is that the wind field shown by the sounding may have been affected by the proximity of the convection itself. However, it was more likely the result of the thunderstorms being based aloft. The inflow into these storms was likely around 2 km at St. Cloud, near the height of the inversion. As seen in the SHARP analysis, the 0-2 km helicity was 806 $m^2\ s^{-2}$. Therefore, much of the helicity shown in the 0-3 km layer was below the inflow into these thunderstorms, and the streamwise vorticity present in this layer was not available to be drawn into the storms by the inflow. Once again, this demonstrates the importance of recognizing the elevated nature of convection in order to analyze the true convective potential of a given meteorological situation.

5. CONCLUSION

The low-level jet has been recognized for many years as a key factor in the development of nocturnal convection over the Plains States. The low-level jet can transport instability northward, enhance low-level wind shear and convergence, and develop strong isentropic upward motion.

At first glance, the convective environment in this case may not have seemed particularly favorable for the development of severe convection. However, an examination of the low-level jet and the factors it affected did show a favorable environment in which severe convection could develop.

Finally, wind profilers were used by forecasters in this event to help track the low-level jet and help in the forecasts of the convection associated with it. With the increased use of tools such as wind profilers and other Doppler radar systems, more will likely be learned about the nocturnal low-level jet and its affects on the weather.

6. REFERENCES

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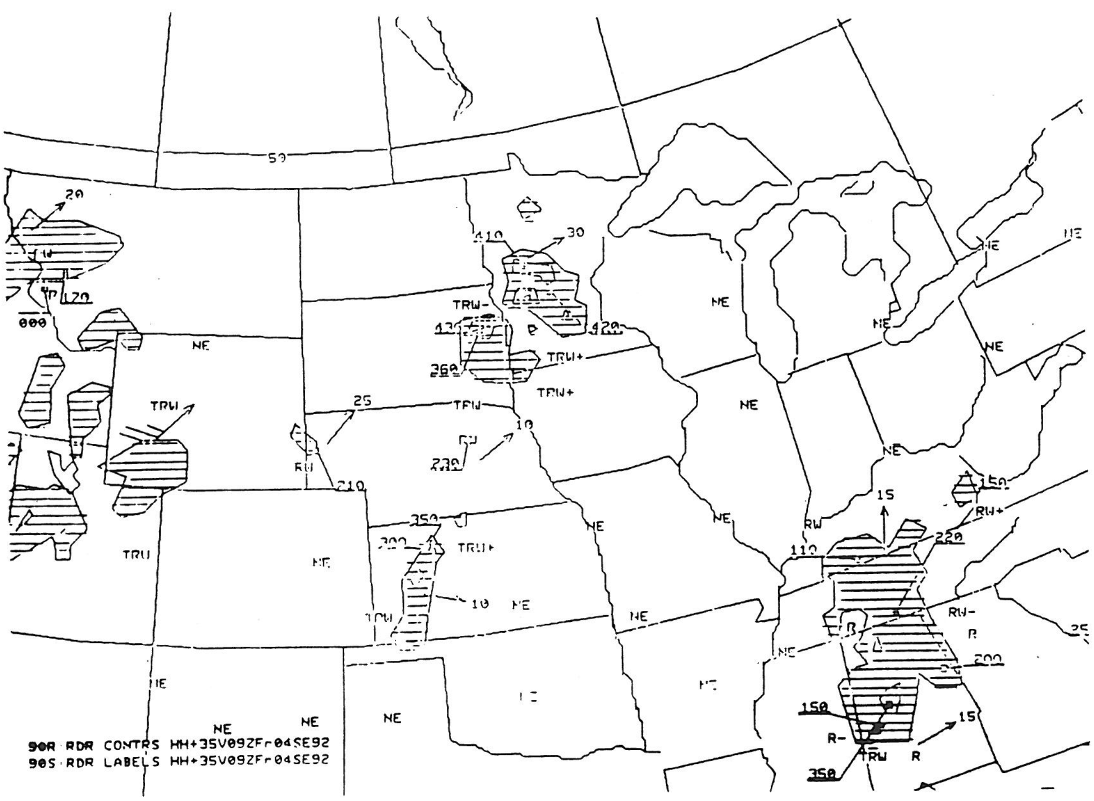

Figure 1. Radar summary chart for 0935 UTC 4 September 1992.

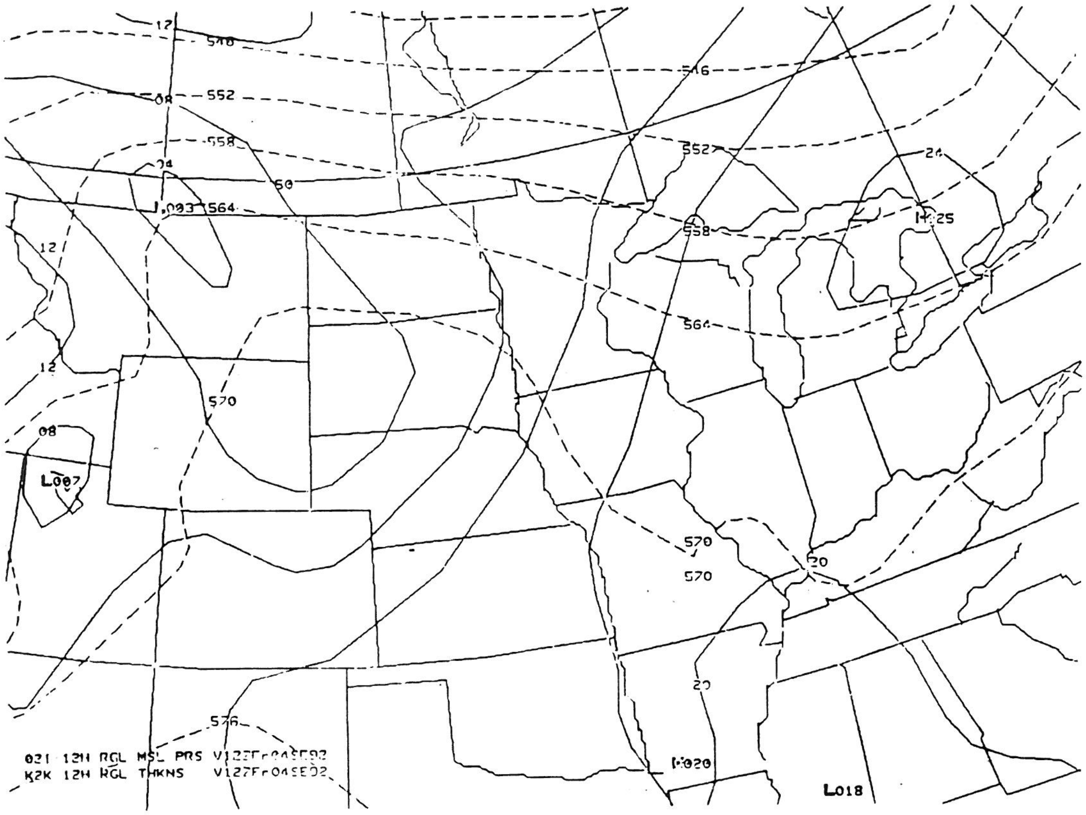

Figure 2. Nested Grid Model (NGM) 12-h forecast of surface pressure (mb, solid lines) and 1000-500 mb thickness (dm, dashed lines) valid for 1200 UTC 4 September 1992.

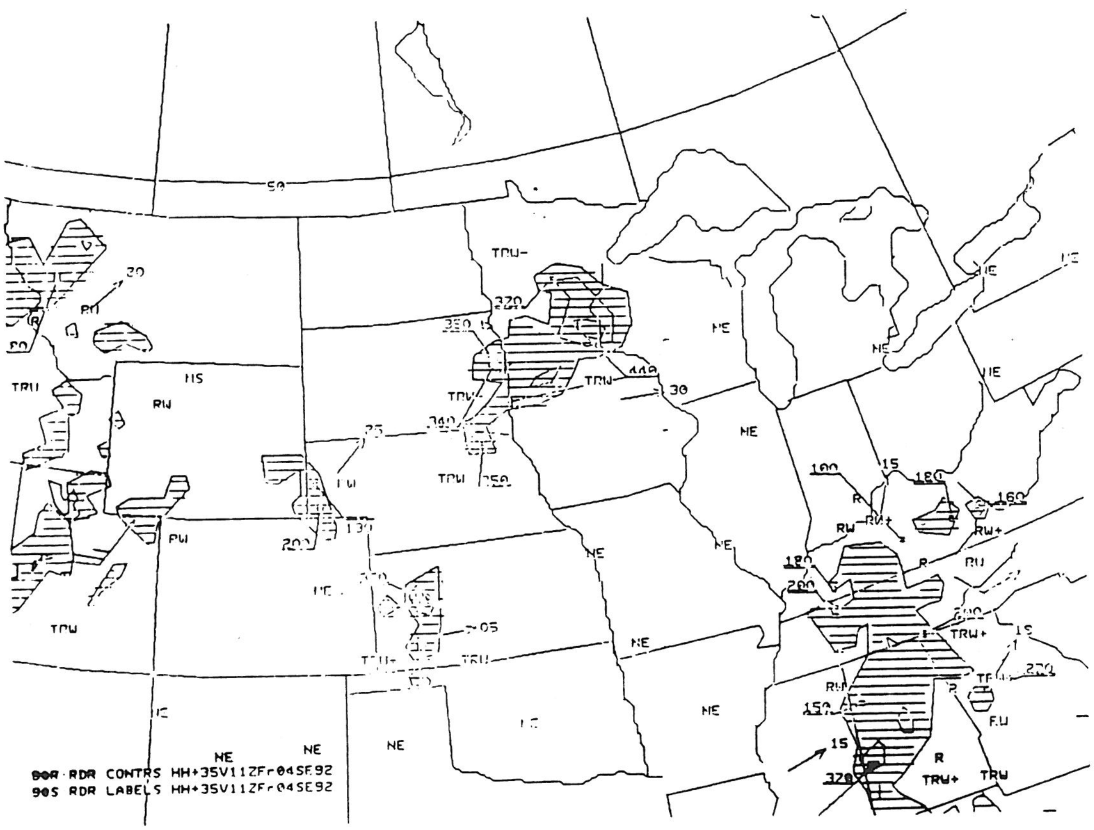

Figure 3. Same as Figure 1, except for 1135 UTC.

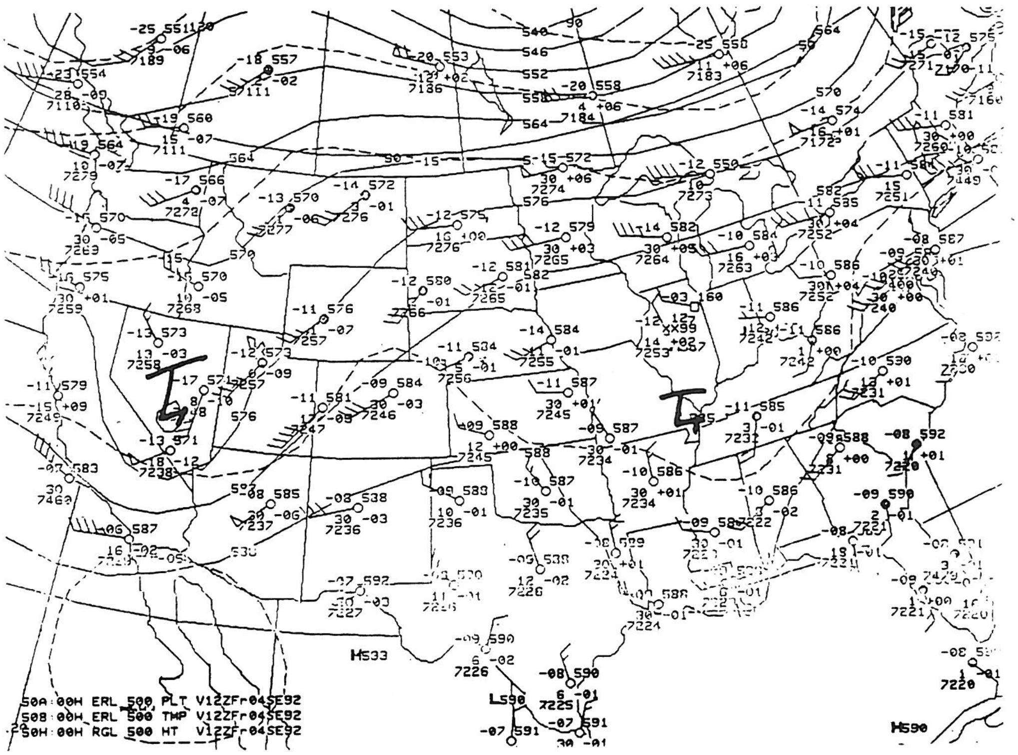

Figure 4. 500-mb analysis for 1200 UTC 4 September 1992. Solid lines are height contours (dm); dashed lines are isotherms (°C).

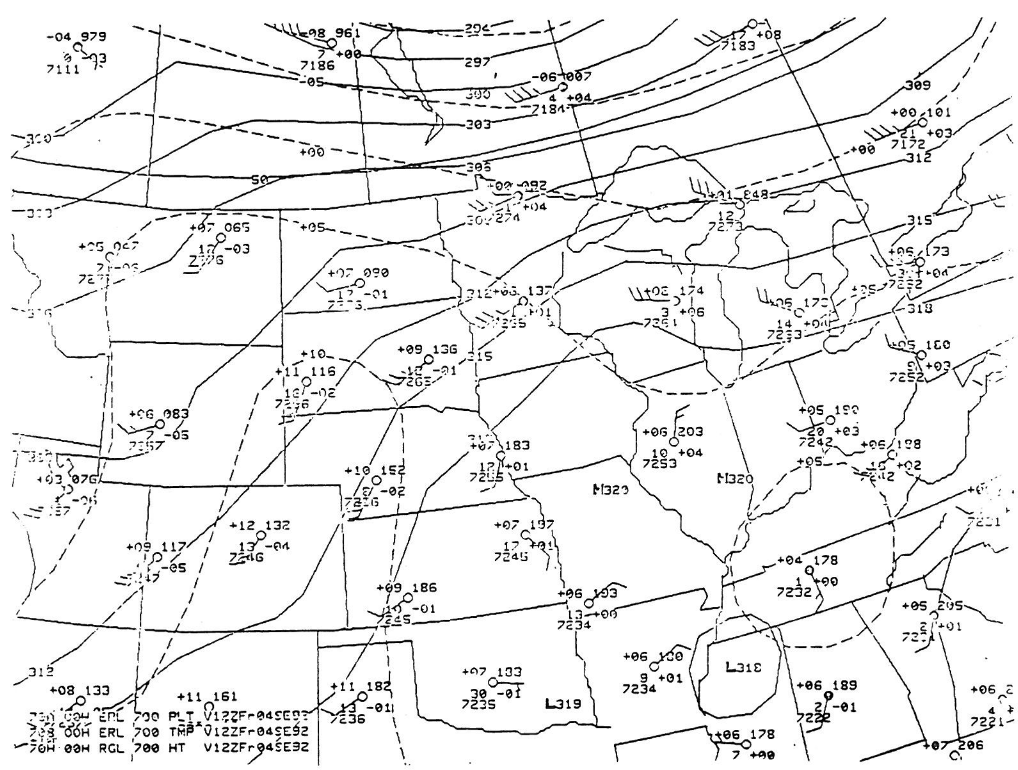

Figure 5. Same as Figure 4, except for 700 mb.

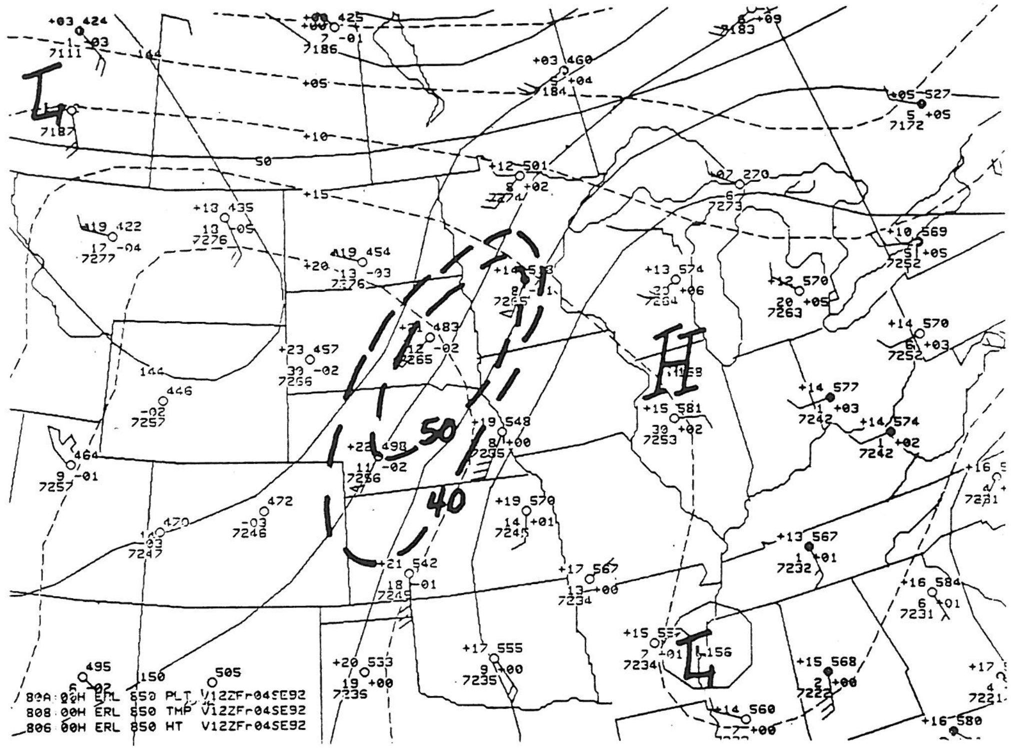

Figure 6. Same as Figure 4, except for 850 mb. Bold dashed lines are isotachs (kt).

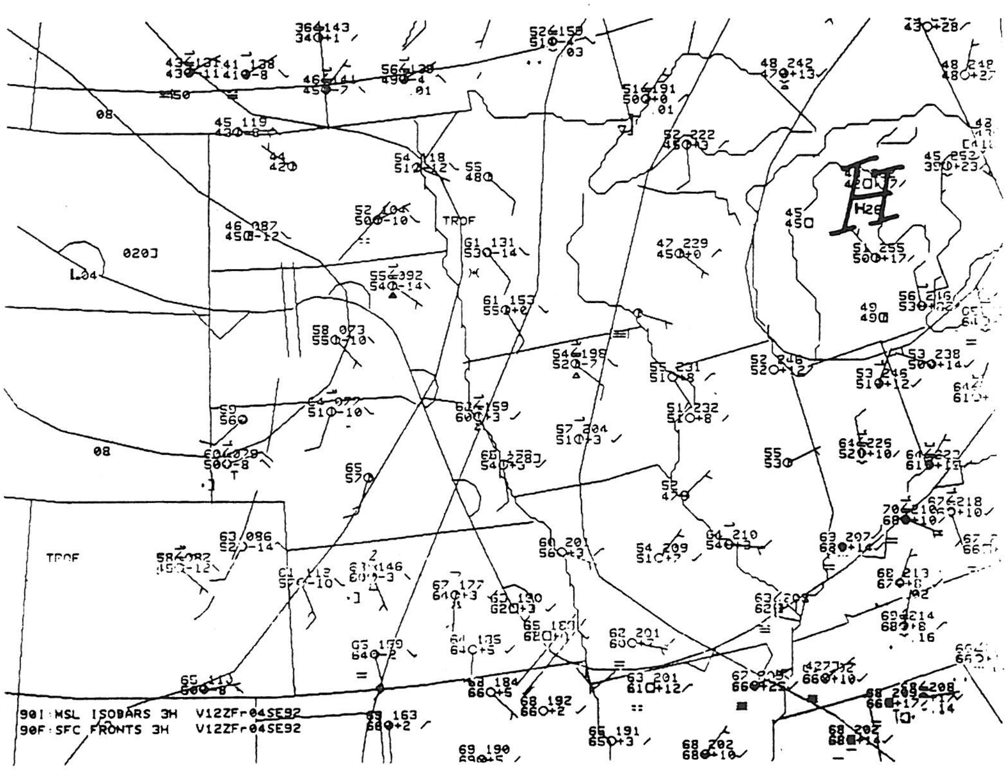

Figure 7. NMC surface analysis for 1200 UTC 4 September 1992.

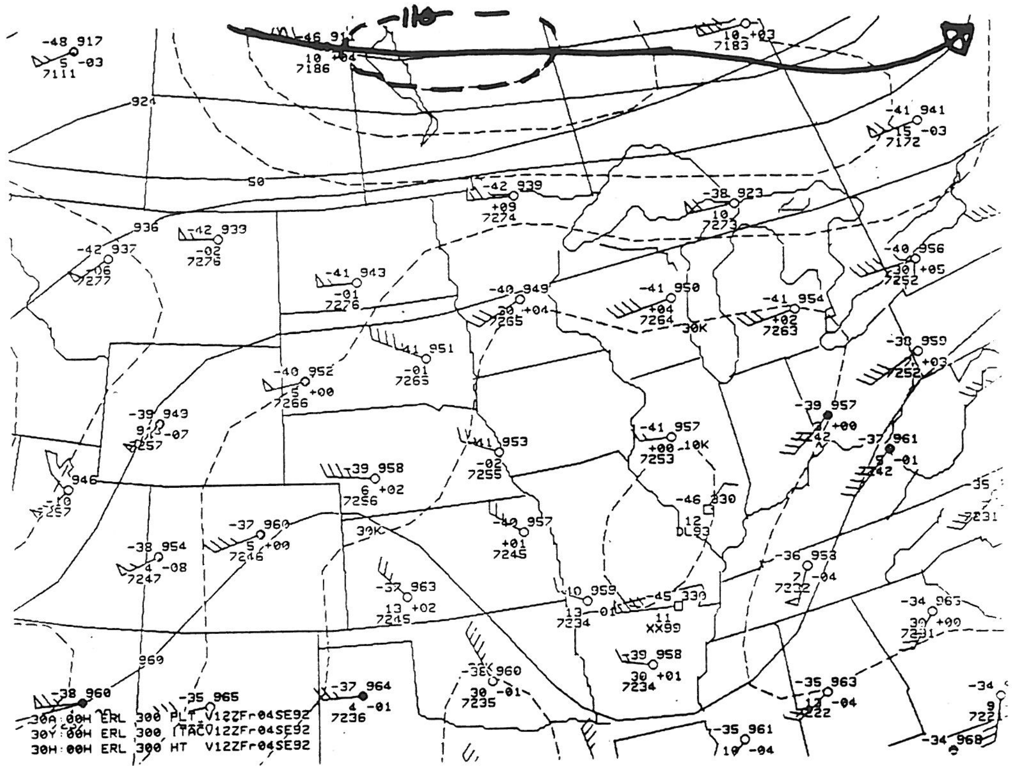

Figure 8. 300-mb analysis for 1200 UTC 4 September 1992. Solid lines are height contours (dm); dashed lines are isotachs (kt).

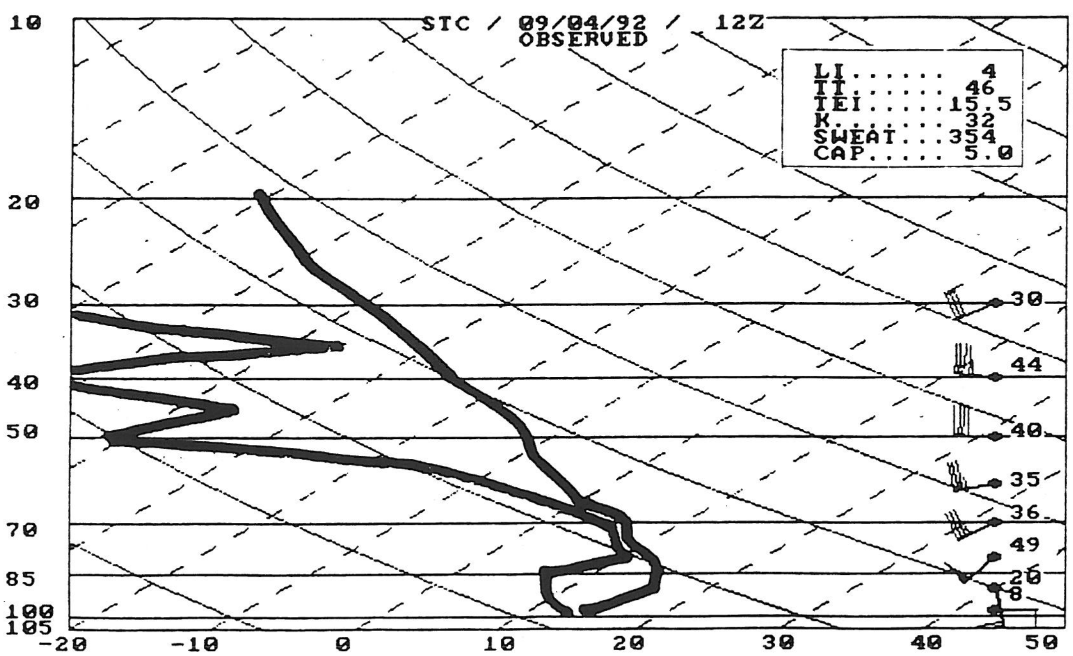

Figure 9. Skew T-log p diagram for St. Cloud, MN (STC), for 1200 UTC 4 September 1992.

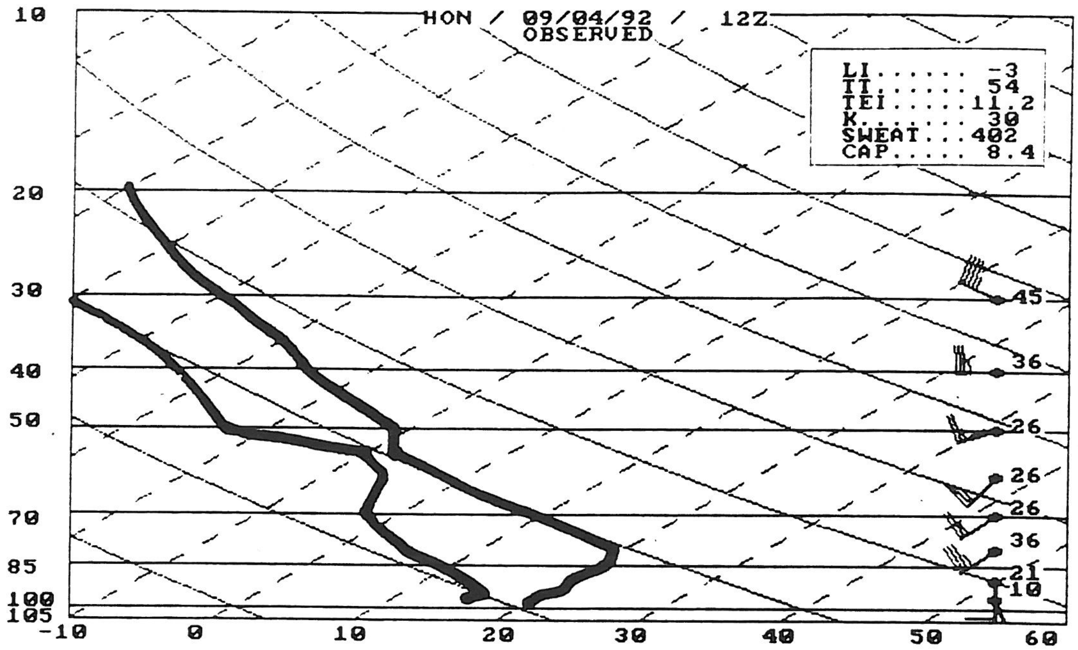

Figure 10. Same as Figure 9, except for Huron, SD (HON).

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WAA AND STG NOCTURNAL JET VRY EVIDENT ON WDL AND NLG PROFILERS THIS AM. WAA
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STATE. WL MENTN RWS THRU MID MORNG ACROSS ALL OF SRN ZNS XCEPT 19..TIMING IN
CONJUNCTION WITH NORMAL DIURNAL WAA PATTERN. NRN 1/2 OF MN SHUD SEE BRKS IN
CLDS ON AND OFF TDY. THE FEW RWS IN NERN MN WL CONTINU THRU AM HOURS. STG WNDS
WL TRANSLATE TO THE SFC BY MID MRNG IN THE WRN 1/2 PROMPTING LWA-S FOR THAT
AREA THRU EVENING. WNDS WL PICK UP DURING THE AFT IN THE ERN 1/2..BUT TO CLOSE
TO CALL ON LWA FOR THIS AREA..SO WL LV THIS DECISION FR NXT SHIFT. NO PRECIP
THIS AFT..BUT THIS EVENING SCT TRWS IN THE WRN 1/3 AS STORM SYS GETS A LTLE
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OVR DKTS THIS AFT MOVS INTO WRN MN THIS EVENG ENHANCING CONVECTN. AS WX SYS OVR
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Figure 11. State forecast discussion (SFD) from WSFO Minneapolis, MN (MSP), at 0838 UTC 4 September 1992.

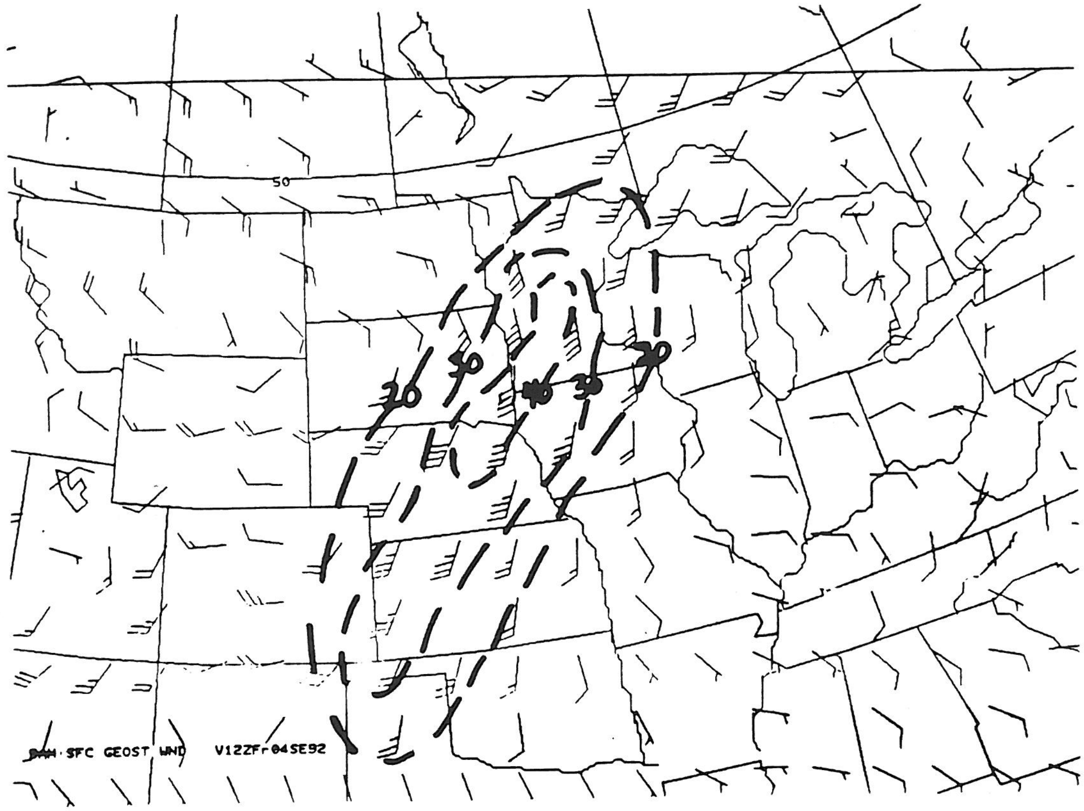

Figure 12. Surface geostrophic winds for 1200 UTC 4 September 1992. Dashed lines are isotachs (kt).

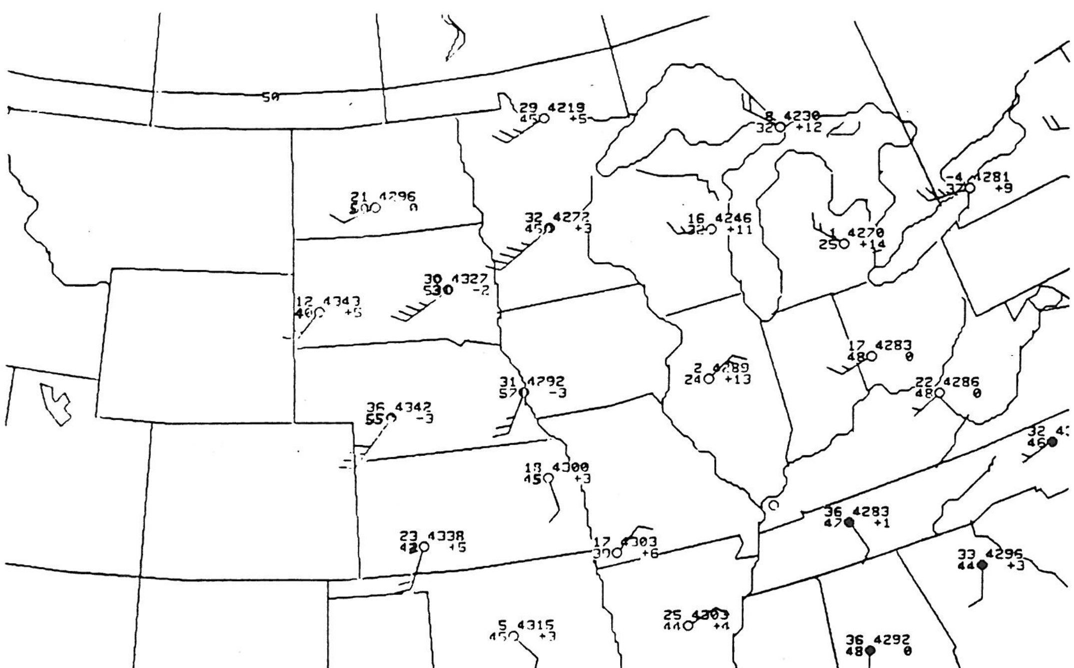

Figure 13. Stability analysis for 1200 UTC 4 September 1992. Upper left hand number of station model is K-index, lower left hand number is the total totals index, upper right hand number is 850-500 mb thickness (dm), and lower right hand number is lifted index. Winds are standard notation for the mean 850-700 mb wind (kt).

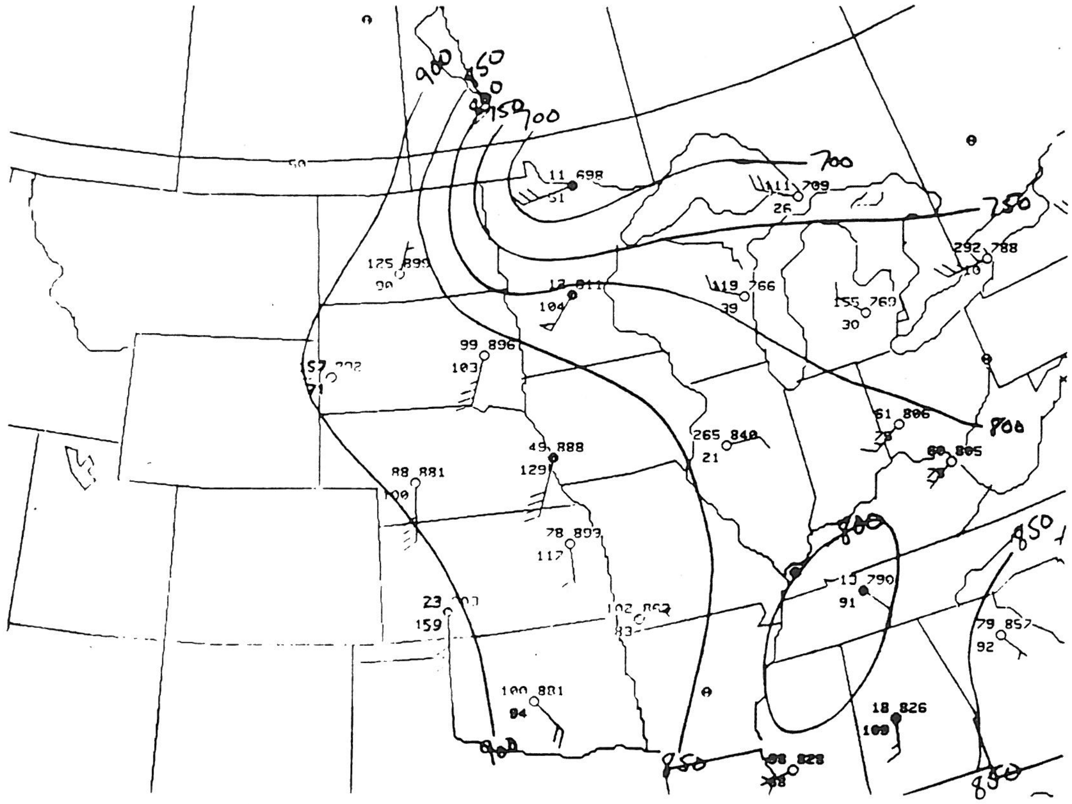

Figure 14. 303 K isentropic analysis for 1200 UTC 4 September 1992. Solid lines are isobars (mb). Upper right hand number of station model is mb of lift needed for saturation, lower left hand number is mixing ratio (10 x g kg^{-1}), and upper right hand number is pressure (mb). Filled circles are stations with a dew point depression ≤ 5°C. Winds are standard notation for the observed wind (kt) at the level closest to the isentropic surface.

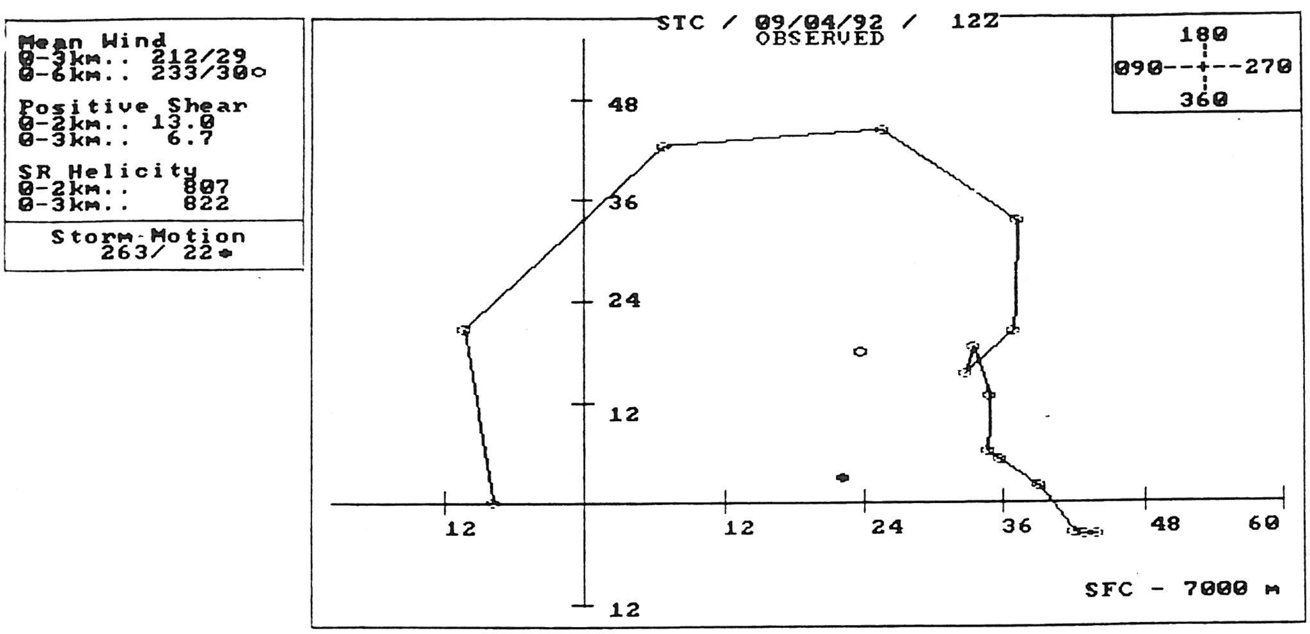

Figure 15. Hodograph for St. Cloud for 1200 UTC 4 September 1992. Winds are in kt. The open circle is the mean wind; the solid circle is the predicted storm motion.